PA197 Secure Network Design
6. Operational Security Management
How to design and manage reliable networks

Eva Hladká, Luděk Matyska

Faculty of Informatics

April 23, 2019

Content

Internet design principles

- Packet switched networks
  - no dedicated resources within the network
  - no fixed route between source and destination
  - accommodates links with different capacity
- Best effort service model
  - no strict guarantees provided
- End-to-end paradigm
  - any features (on top of the actual packet delivery) are to be provided by the higher level protocols at source and destination nodes only
- Implications:
  - scalable and robust network
  - no explicit security considerations
  - too open to malevolent exploitation

Network design example

- Paraphrasing from the CISCO Network Design principles
  - `http://www.pearsonhighered.com/samplechapter/1587132125.pdf`
- 1st step: Network requirements
  - 24/7 operation even if a node/service or link fails
  - data is transmitted in a timely manner
  - protect data transmitted and stored
  - allow for modifications and grows
  - fixing failures should be easy and fast
- 2nd step: Requirements translated into Design goals
  - scalability
  - availability
  - security
  - manageability

Network design example II

- CISCO proposes Hierarchical design
  - group devices into multiple networks
  - organize network in a layered approach
    1. core layer
    2. distribution layer
    3. access layer
- Advantages
  - local traffic remains local
  - encapsulation, different rules for different places (local networks)
  - this also increases reliability of different layers

Network design example III

- Roles of individual layers
- Core layer
  - 100 % uptime
  - maximizing throughput
  - facilitate network grows
- Distribution layer
  - filtering and managing traffic flows
  - enforcing access control policies
  - summarizing routes before advertising them
  - isolating core from access layer failures
- Access layer
  - controls user access to the network
  - QoS considerations
  - security policies enforcement

Internet architecture shortcomings

- No explicit security incorporated
  - no field in the packet is protected
  - easy to forge any identity
  - easy to forge source address
- No strict (hierarchical) structure of the management
  - local management "islands" without mutual influence
    - a robust solution
    - loss of control beyond islands' borders
- Problem of security of end nodes
  - holes in operating systems' security
  - devices (including the active elements on the network) with security holes and/or default passwords
  - easy to send "untraceable" packets
    - tracing beyond own management edge needs cooperation

Improvements of Internet architecture?

- Gradual improvements rather difficult
  - a complex interplay between protocols
- Adding a “security layer” is not sufficient
  - one layer will not be sufficient
    - attacker could use not-secured layer(s)
  - both transport and semantics of data must be secured
  - also end nodes can not be left unattended
- Nevertheless we must do what is possible
  - in parallel to more ambitious plans

Access control

- In Internet, if you have physical access to the network, you are in
  - no access control in standard Internet protocols
- Authentication
  - know who is speaking
  - know who is doing something
    - all not directly possible in the current Internet
  - but the necessary first step for access control
- Authorization
  - "another name" for access control
  - restricts what can be done by whom

Access control II

- Basic principle: minimal rights
    - start with an absolute minimum
    - rise access rights on request
        - and check repeatedly who is there
- Drawback: limited freedom
    - one of the major reasons why it is so difficult to make Internet more secure
    - remember the control part
        - you never know who will exert the control in the future

Limited management authorization

- Implementation of the restricted access right to the network management
- A very general concept
  - the general management theory
  - not restricted to networks or information technology only
  - need to know principle
  - split of decision rights among several players
- IT made the need for control more needed/explicit
  - remote decisions
  - no human check of the orders
  - extremely fast reaction time
- Least privilege principle
  - abstraction layers
  - start with the least privilege (access rights)
  - add more rights (increase the privilege) on the go as needed
    - usually requires repeated authentication

Least privilege

- Several synonyms
  - least authority
  - minimal privilege
- A mitigation against both
  - bugs and faults (fault tolerance)
  - malicious use (security)

  in both cases it increases reliability of the system
- More a principle than a precise set of rules
  - not easy do define the minimal privilege actually needed to perform an operation
  - more a human decision what is needed

Abstraction layers

- Abstraction layers in the active network elements
  - usually very limited set of layers in the standard elements
    - read vs. read/write access and user vs. administrator
  - even the read access can be dangerous
    - misuse of SNMP complex call requiring lot of processing power to get all the information
    - simultaneous read requests
- One source of interest for Software Defined Networks

US Critical infrastructure

- US definition:
  - Critical infrastructure are the assets, systems, and networks, whether physical or virtual, so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof.

  Department of Homeland Security `www.dhs.gov/what-critical-infrastructure`)
  - many sectors, important for us are Communications and Information Technology ones
    - Office of Cyber security and Communications
    - responsible for enhancing the security, resilience, and reliability of the Nation's cyber and communications infrastructure
- Understanding that attack on network (and cybersystems in general) could have very serious impacts on the whole national wellbeing (and its security)

Cyber-physical systems

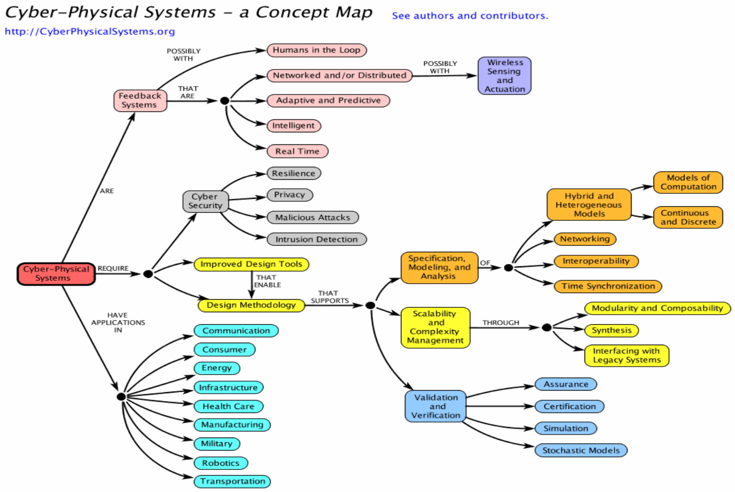
- Computer systems (elements) controlling physical systems (entities)
  - *Embedded systems* a special (or predecessor) case
  - Examples in energy distribution, aerospace, autonomous automotive systems, process control systems in factories, (medical) monitoring etc.
- The major purpose is the physical expression, not computations (the digital part)
- More and more network connected
  - part of the Internet of Things
  - increased vulnerability

Connectivity adds value but also risks

Cyber-physical systems II

- For attacker, the physical manifestation is important
  - but the attack is led through the digital (cyber) part
    - the classical physical security may not be sufficient
    - the cyber part deserves equal (or even higher) protection
- See also `http://CyberPhysicalSystems.org`
  - the mental map on the next slide is taken from that source

Cyber-physical systems—Mental map



Control plane

- Two basic abstraction layers
  - data plane—all the users' traffic goes here; also called forwarding plane
  - control plane—the network management information
- Usually, the data and control plane share the same physical infrastructure
  - very convenient, easy to implement
  - opened to attacks
    - both passive and active attack modes

Control plane II

- Situation more confused when users' step in
  - VPN vs openVPN
    - VPN part of the network management, its control (management) messages) understood by network active elements
    - openVPN a software product, runs within the data plane, "hidden" from the network management
  - IDS systems looking both for data and control packets
- Don't mess with physical vs digital infrastructure
  - control plane part of the digital
  - however could run on a separate physical infrastructure

Physical security

- Physical layer the lowest layer of any communication network
- Security and reliability of the physical layer critical for all the above layers
  - however, with redundancy and fast recovery we may create more resilient networks even with not resilient physical layer
- Physical reliability
  - redundant independent connections
  - multihome nodes and multirouting protocols
- The physical security of critical nodes
  - limited access to the sites with
    - management systems
    - critical active elements

Physical security II

- Impossible to control the whole network
  - redundancy, independent paths
  - wired (optical) and wireless networks
- Important to check whole paths for independency
  - e.g. a bridge aggregating all otherwise independent physical lines

Digital security

- Data and control plane
- Time critical information
  - esp. in the control plane
  - timeouts may lead to wrong conclusions about the state of the network
- Reliable protocols
  - both the architecture and the implementation
  - software engineering practices
    - Ada used for mission critical systems for the USA DoD

Digital security II

- Authentication and authorization
  - distinct requirements for data and control plane
  - essential for the control plane
    - no anonymous actions/users
    - strict access control with the least privilege principle applied
  - strong authentication (two factor, . . .) for some operations
  - organizational policies very important
    - a principle of "four eyes" (two persons) is forsaken if the same person keeps both digital credentials

Digital security III

- Encryption
  - both data and control packets
- Specific requirements for control plane
  - cross domain encryption
  - PKI vs. symmetric keys exchange
- Accounting
  - keep track of the actions taken
- Reliability of accounting data
  - remote data collection
  - size of the data/lossy aggregation over the time

Cost of higher security requirements

- Explicit
  - less easy access to the network
  - more complex protocols
  - high processing needs (authentication, encryption)
  - slower response time
    - for (repeated) authentication
    - for access right decisions
    - for continuous control of access privilege
  - higher management burden
    - must define, implement and control policies
  - higher operational costs
    - keys, policies, accounting, . . .

Cost of higher security requirements

- Implicit
  - higher control could mean less freedom
  - in strictly hierarchical systems, compromising the highest layer could be disastrous
  - in too complex systems people start to bypass the rules and policies
    - a conflict between "have things done" and "check every step"
  - the natural world is imperfect and does not fully fit into strict mechanical rules

SDN principles

- A network with clear separation between control and forwarding plane, where the control plane spans/controls several devices
- Features:
  - makes control plan directly programmable
  - abstracts the underlying infrastructure
- SDNs present a reaction to
  - limits of vendor based solutions
  - requirements of more dynamic access patters (mobile, remote, . . .)

SDN advantages

- directly programmable and forwarding independent control
- programmatically configurable not vendor locked
- central management of several devices: the concept of network controllers that
  - maintain a (global) view of the network
  - provide a single interface to applications and services
  - mimic a single active element (switch)
- flexible allow fast (programmed) reaction to events and changing environments
  - including profound changes in traffic flow (routing)

SDN architecture

- Three different layers
  - the major difference is in the interaction, not the layers themselves
- Application and orchestration layer
  - focuses on expansion of network services
  - examples are cloud orchestration network virtualization, QoS, . . .
- Control plane layer
  - logically-centralized SDN controller
  - exposes clearly defined APIs to Application layer
  - performs consolidated management and monitoring of network devices
- Data plane layer
  - physical network equipment
  - programmable

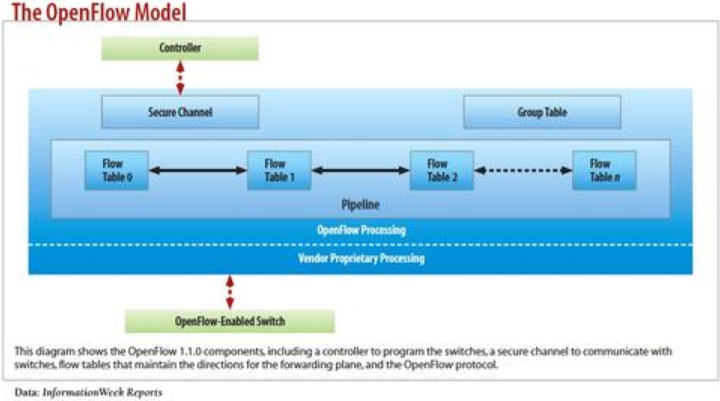
SDN

- Controllers
  - keep the network intelligence
  - allow to provide a central (global) view on the whole network
    - in contrast to the current distributed approaches
  - controller provides a programmatic API to the network
- Security
  - benefits of a central controller for distributed attacks
  - DDoS attack, botnet or worm propagation
  - controller's global view allows collecting traffic information that could be fed to a specific IDS for attack recognition
  - controller's central role allows for fast reaction at the or near real sources of attack

OpenFlow protocol

- A communication protocol
  - gives programmable access to the switch forwarding plane
  - enables to determine a path of packets through a network of switches
- Function: Remote administration of packet forwarding tables (layer 3)
- Routing decisions taken by the controller
  - translated into rules and tables
  - implemented at wire speed by the device
- Properties
  - uses TCP, port 6653
  - TLS mandatory
- Security implications
  - central controller a central point of attack/failure
  - TLS faults susceptible

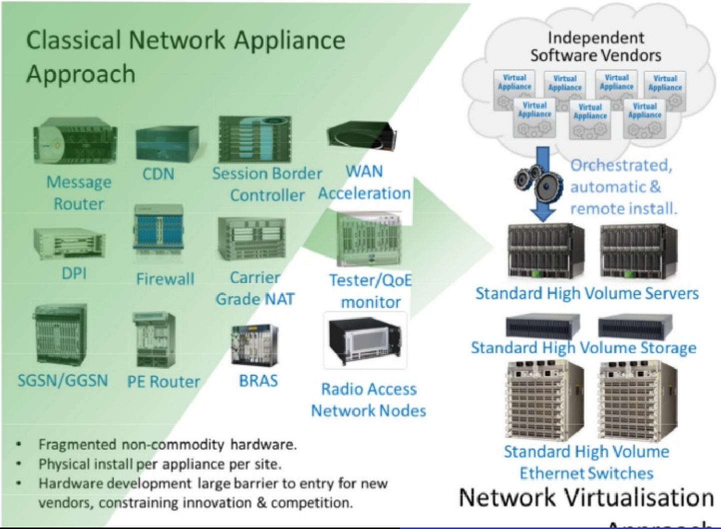
OpenFlow Model



Network Functions Virtualization

- A complementary activity to SDN
  - not dependent, but beneficial
- Aim is to consolidate network equipment types
  - leveraging virtualization technology
  - reducing the number of network device types
  - exposing their functionality through clearly defined APIs
- NFV support to SDN
  - standardized programmable network interfaces
  - use of commodity servers and switches

NFV Approach



Why clean-slate design?

- Need for fundamental changes in Internet architecture
  - flaws in the current Internet architecture
  - incremental changes may not by sufficient (see IPv6 example)
- A research activity
  - to investigate options
- RINA as an example
  - `http://www.cs.bu.edu/fac/matta/Papers/rina-security.pdf`
  - `http://irati.eu/wp-content/uploads/2013/01/6-Security130123.pdf`

RINA

- Recursive InterNetwork Architecture (Boston University)
- Basic premise: *Network is only Inter-Process Communication (IPC)*
- IPC a function to allow two processes (sender and receiver) to communicate
  - process names are identifiers
  - IPC function examples: process location, permissions determination, passing information, ...
- Security by isolation
  - hosts can not address any element of the ISP
  - no hacker can compromise ISP assets
    - unless ISP is physically compromised

RINA II

- *Distributed IPC Facility (DIF)*
  - an organizing structure
  - "medium" for communication
  - processes can communicate only if they belong to the same DIF
    - a layer in a standard architecture
  - allows processes to allocate flow between them
    - providing names for the processes
    - and flow characteristics (bounds on data delay, jitter, loss, reliability, . . .)
  - supports recursivity
    - a group of processes connected through DIF could play a role of a process in a different DIF

RINA III

- Security mechanisms
  - mandatory authentication before joining DIF
    - a process does not know any addresses nor "well known ports", all is provided after authentication by the appropriate DIF
  - node addresses are internal to DIF, not exposed to the applications
  - data connections are dynamically assigned connection-endpoints IDs
    - bound to dynamically assigned ports
  - DIFs are securable containers, so no need for firewalls
- Security implications
  - resiliency to transport attacks
  - clear security borders
  - complexity of RINA security is lower than the security of the current Internet
    - much lower number of protocols and security mechanisms

Summary

- Secure network design
  - access control and the least privilege principle
  - redundancy
  - clear role separation
- Critical infrastructure and cyber-critical systems
  - attack through the digital, not physical components
  - physical and digital security recapitulation
- Software defined network
  - overcoming many current drawbacks
  - incremental changes to the network design
  - centralized control
- Clear slate design and RINA
  - far reaching vision
- Next session: Network monitoring and defense